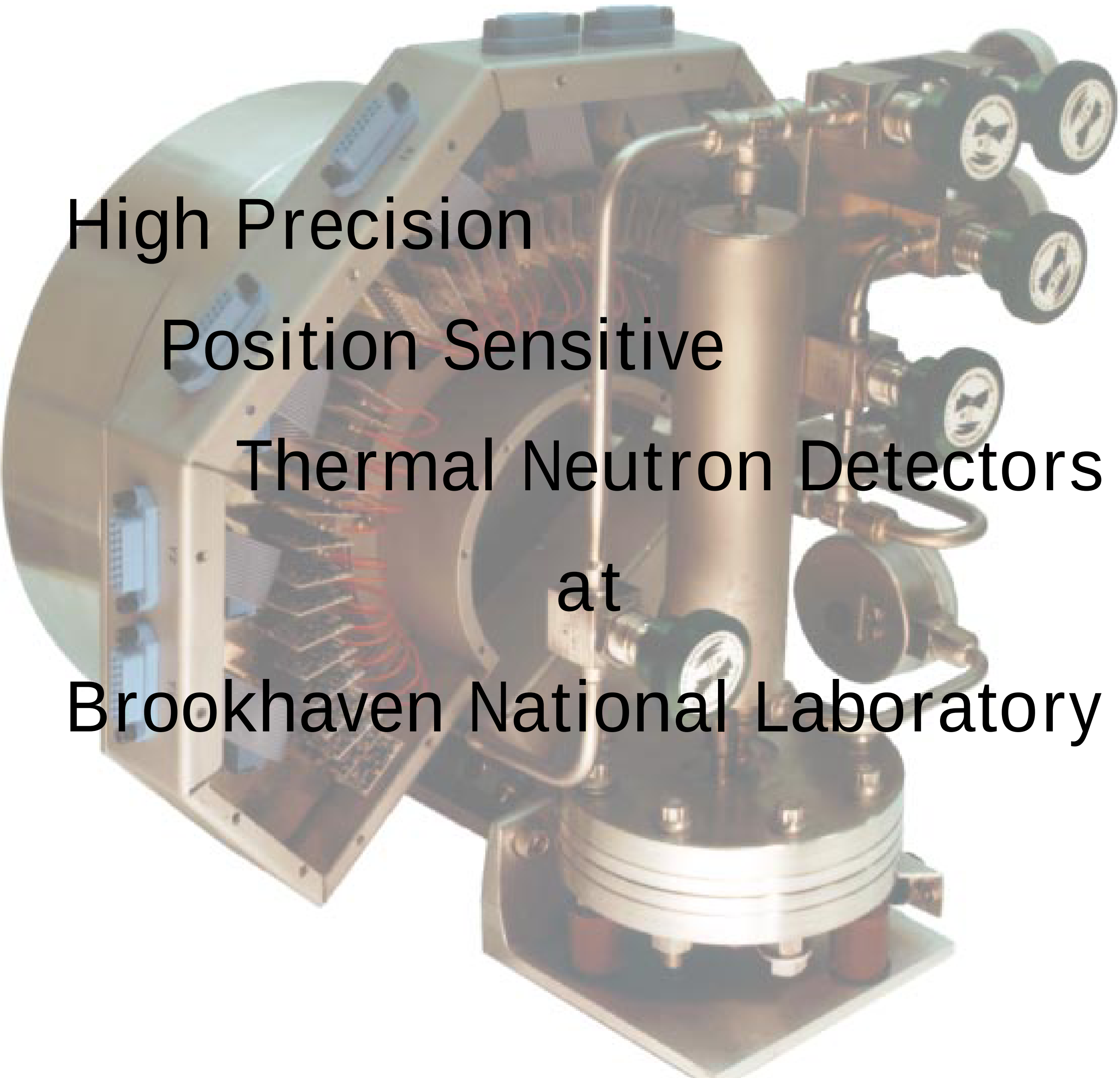


High Precision Position Sensitive Thermal Neutron Detectors at Brookhaven National Laboratory

January 2001

High Precision Thermal Neutron Detectors at Brookhaven National Laboratory

The Instrumentation Division at Brookhaven National Laboratory carries out an R&D program focused on high precision position sensitive thermal neutron detectors, primarily in support of Structural Biology and Chemistry research at the nation's steady state and spallation sources.

- All detectors are ^{3}He filled multiwire proportional chambers with interpolating cathode readout. They provide excellent position resolution, efficiency, counting rate, timing resolution and low sensitivity to gamma radiation, and are especially distinguished with respect to stability of recorded neutron position, dynamic range and lack of blooming effects.

- A variety of detector configurations have been implemented with sensitive areas ranging from 5 cm×5 cm to 50 cm×50 cm, including detector arrays comprised of three 20 cm×20 cm detectors.

- Existing detectors have proved to be reliable and invaluable working tools for researchers at BNL for over ten years. Measurements of position resolution performed with these detectors are unsurpassed by any detector group in the world.

- A 120° curved detector with an arc length of 1.5m is almost completed for a protein crystallography station at the Los Alamos Neutron Scattering Center (LANSCE). The high counting rate and time resolving capabilities of this detector will permit full utilization of the super Laue technique at the Los Alamos Pulsed Spallation Neutron Source.

Thermal Neutron Detection

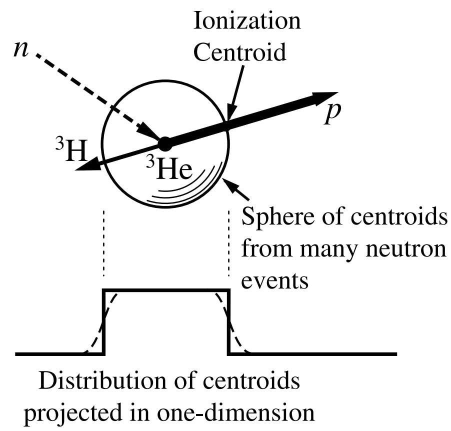
— Basic Operating Principles

The Nuclear Reaction

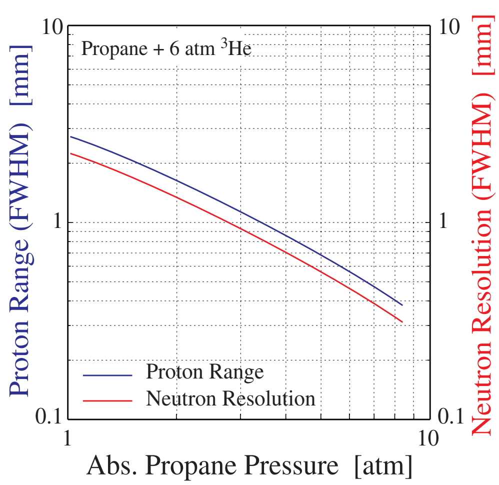
Thermal neutrons convert in ^{3}He through this reaction:

$$^3\text{He} + \text{n} \rightarrow {}^3\text{H} + \text{p} + 764 \text{ keV}.$$

The reaction products, a 191 keV triton and a 573 keV proton, are emitted in opposite directions. The ionization centroid of the two particle tracks is displaced from the neutron interaction position because the proton is more heavily ionizing than the triton, and also has a larger range. This displaced centroid is measured by the position-sensitive detector.



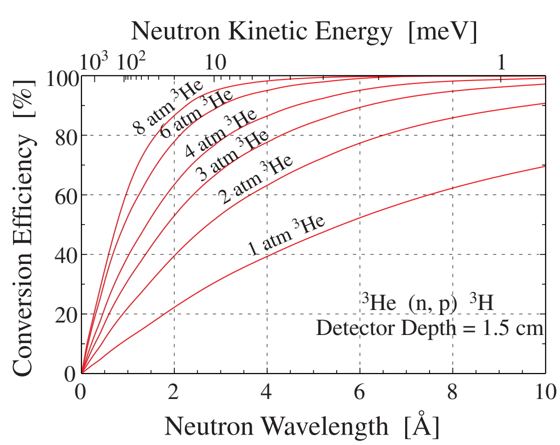
Position Resolution Limit



When projected in one dimension, the loci of centroids from many events describe a rectangular distribution whose width is equal to the diameter of the sphere. To a good approximation, the FWHM position resolution is 80% of the proton range, which varies inversely with the gas density. To achieve resolution in the millimeter range, an additional gas is needed to provide stopping power for the proton and triton. Propane is chosen as the optimum additive for these proportional chambers because of its high stopping power and low sensitivity to gamma radiation.

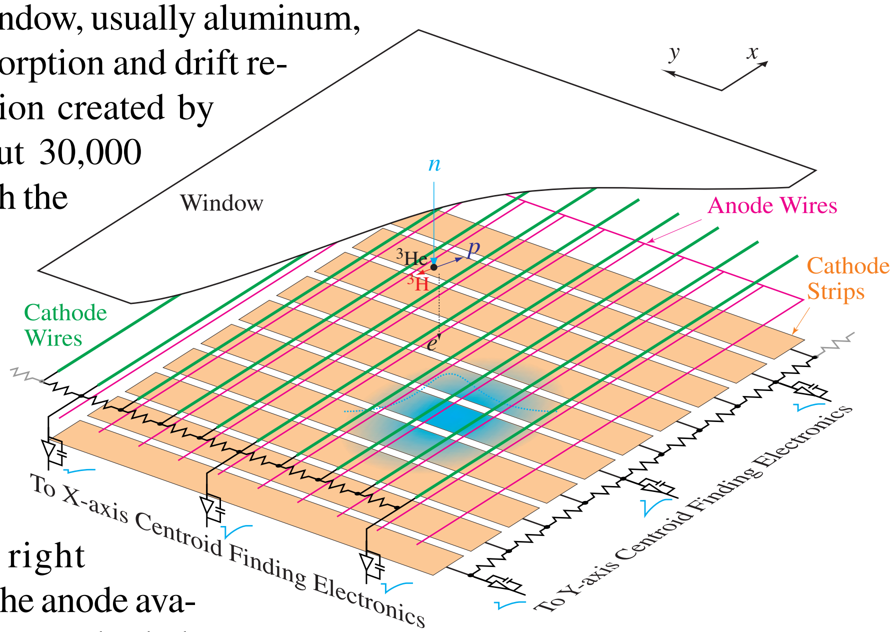
Detection Efficiency

For a thermal neutron chamber with a gas depth of 1.5 cm, the detection efficiency over a range of operating gas pressures is shown to the right. Very high detection efficiencies can be achieved for cold neutrons, around 9Å, with just 1 to 2 atm. of ^{3}He. As wavelength decreases, efficiency falls, but even at 1 Å an efficiency of about 50% can be achieved with 6 atm. of ^{3}He. The detection efficiency of this class of detector is better than, or as good as, that of other detecting media.

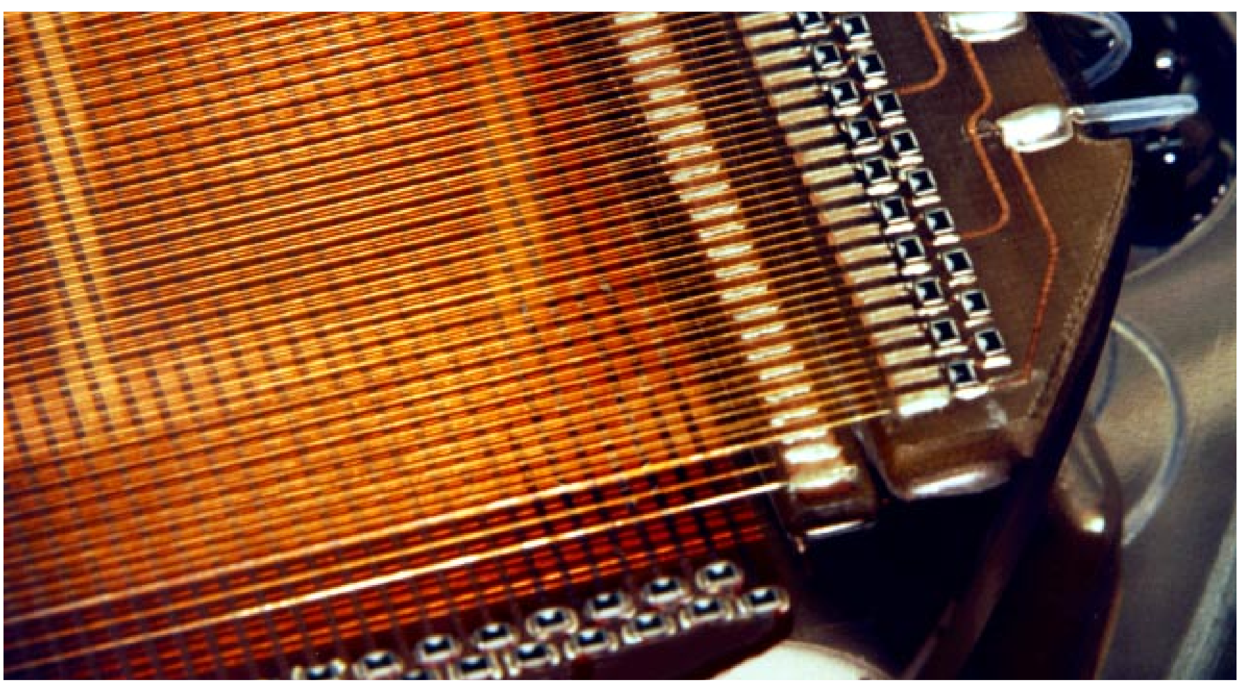


Thermal Neutron Detection

— Position Sensing



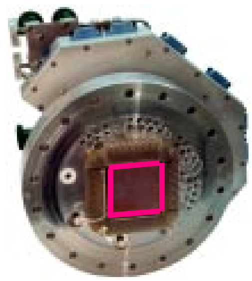
Neutrons enter through a window, usually aluminum, and most convert in the absorption and drift region. The primary ionization created by the proton and triton, about 30,000 electrons, then drifts through the upper wire cathode and an avalanche takes place on the nearest anode wire, or wires. The upper cathode wires and anode wires normally run in the same direction. The lower cathode has metal strips, running at right angles to the anode wires. The anode avalanche induces positive charge on both the upper and lower cathodes. The sampling of induced charge with cathode wires or strips yields the center of gravity of the anode avalanche with high precision when appropriate design criteria are followed. The numerous readout nodes along both axes are fixed in space. They act as fiducial marks, ensuring a high level of position stability.



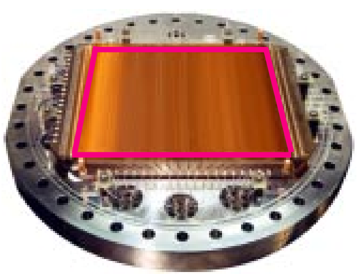
Corner of electrode structure inside a 20cm×20cm detector, showing upper cathode wires, anode wires, and lower cathode strips on glass plate.

High Precision Thermal Neutron Detectors

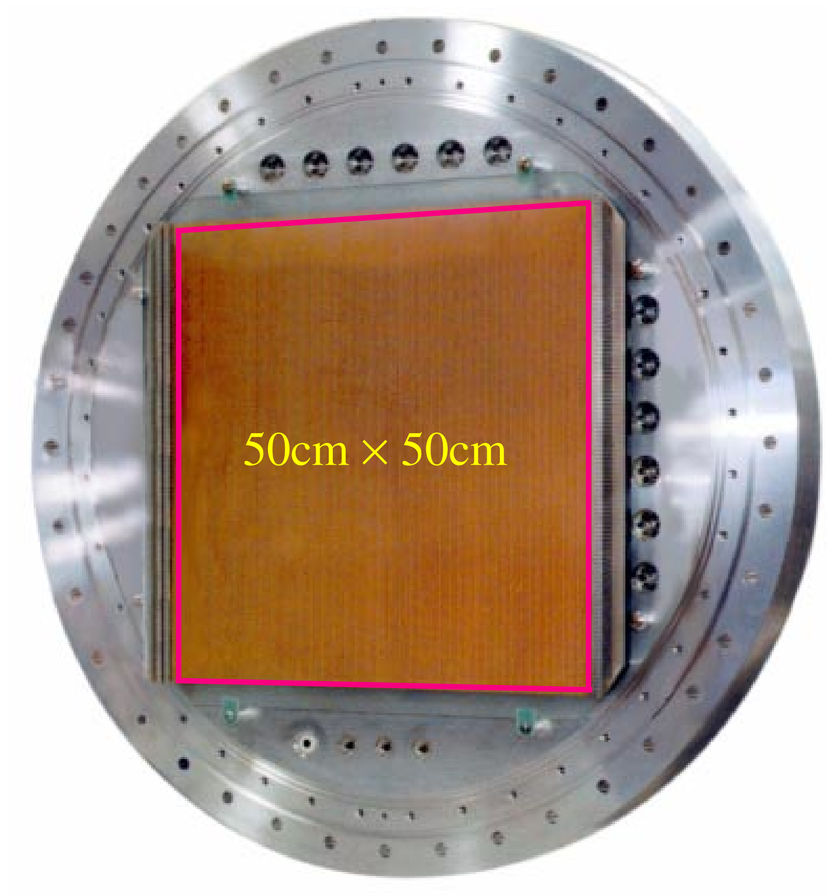
The Family Album

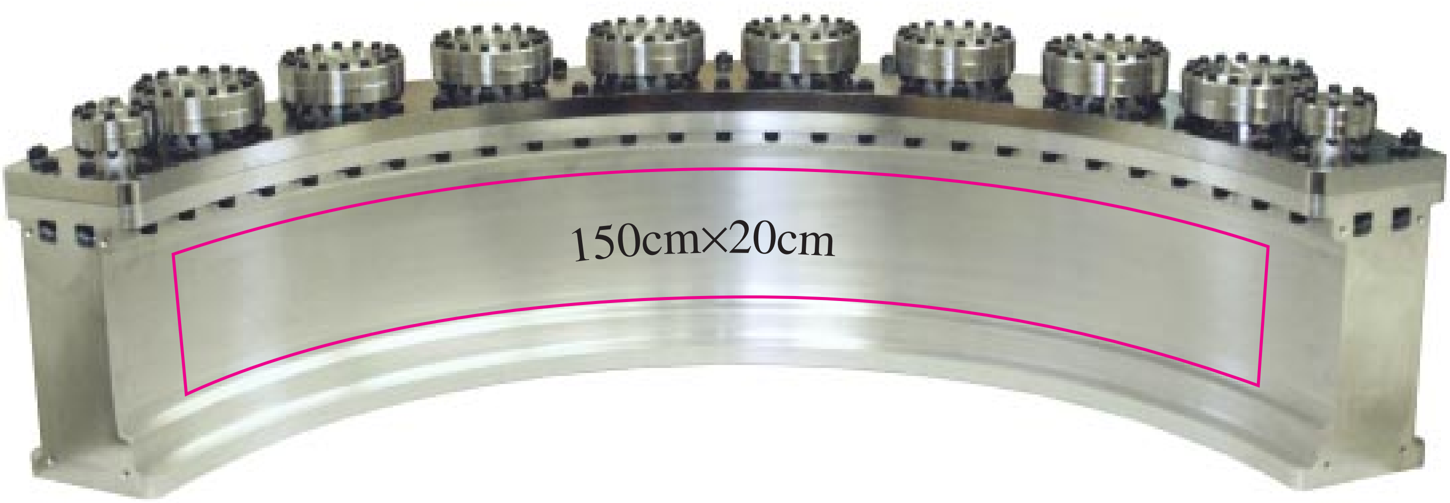


5cm × 5cm

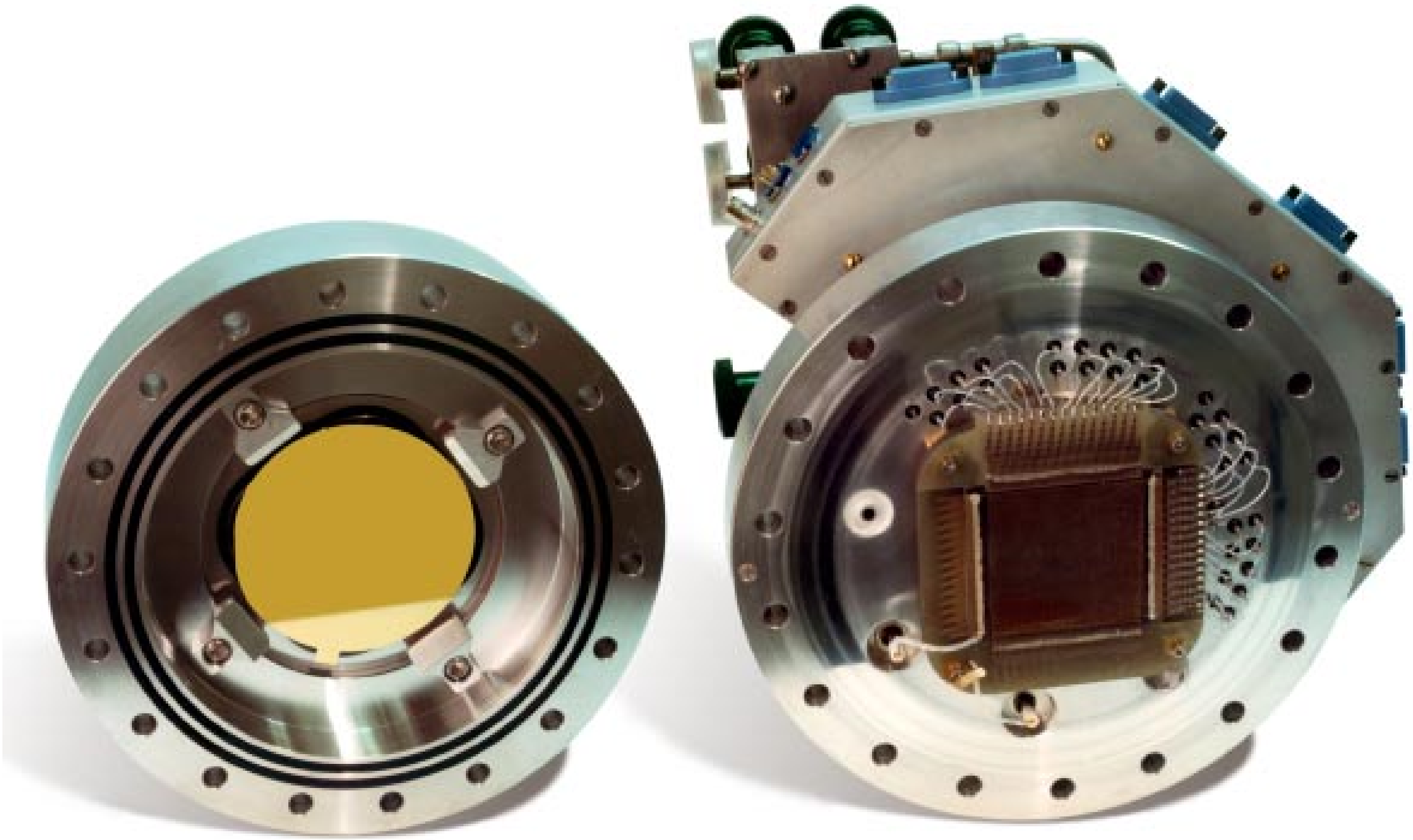


20cm × 20cm



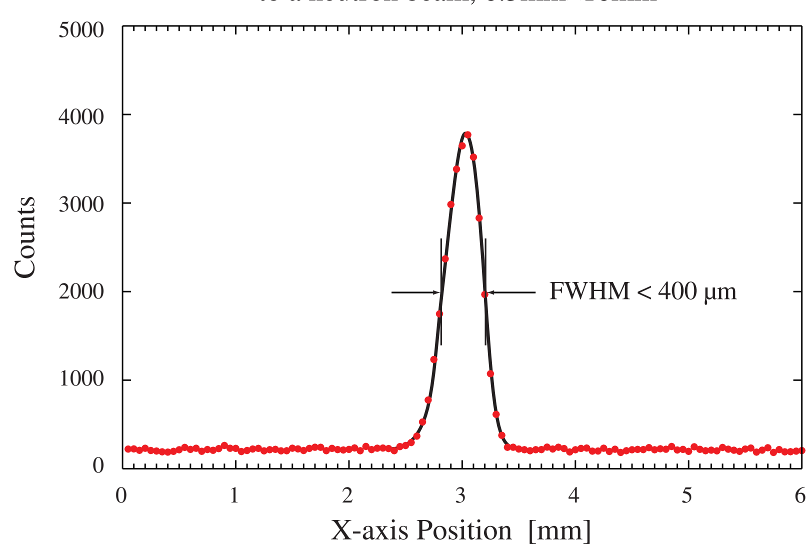


High Precision 5cm×5cm Detector

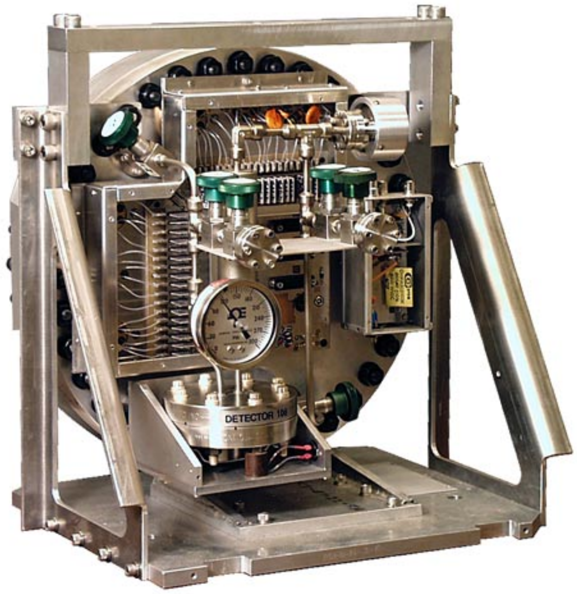


The 5cm×5cm detector contains an entrance window of sapphire (above, gold plated on the inside). The detector, filled with a partial pressure of 6 atm. of propane, achieved a position resolution of better than 400μm FWHM. This represents the best resolution ever recorded in a gas-filled thermal neutron detector (figure to right).

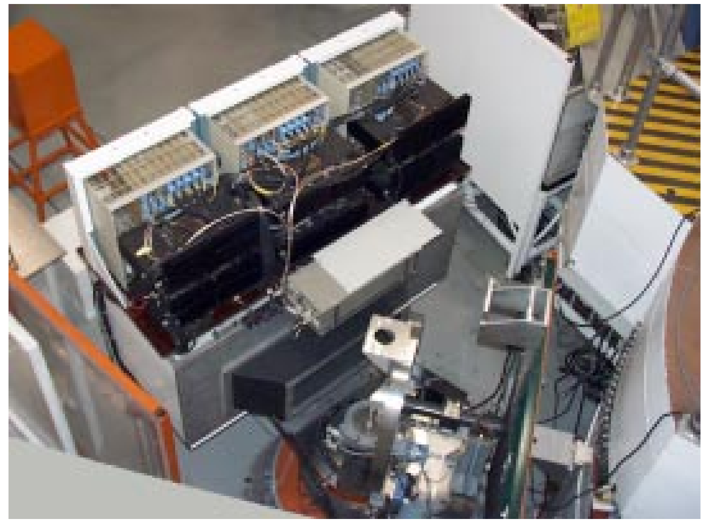
Position response of 5cm×5cm detector
to a neutron beam, 0.3mm×10mm



High Precision 20cm×20cm Detectors



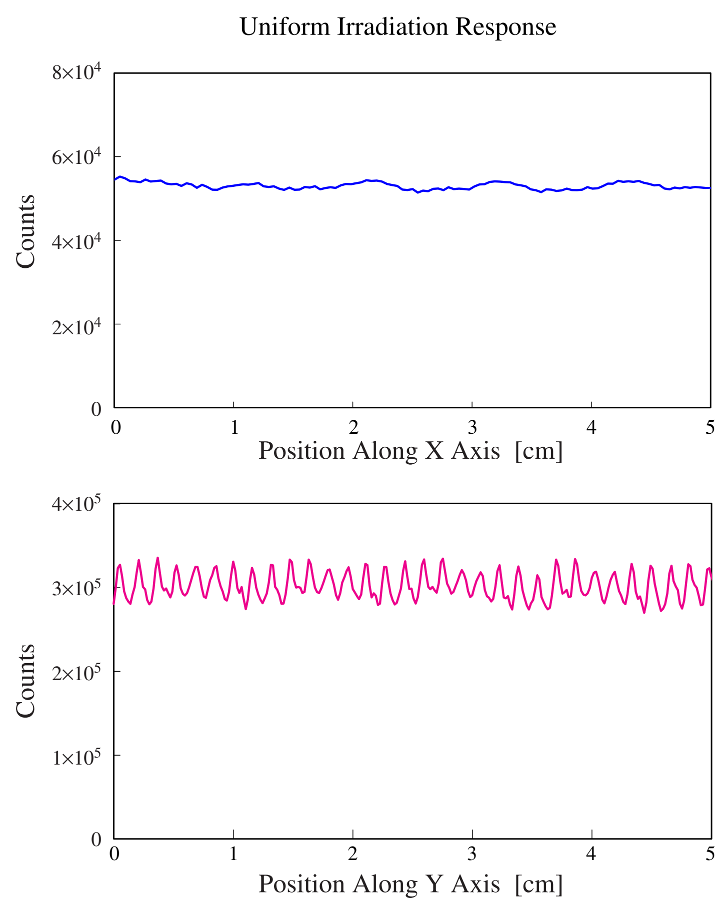
Rear view of a detector showing signal feedthroughs and preamplifiers, as well as the gas purification system.



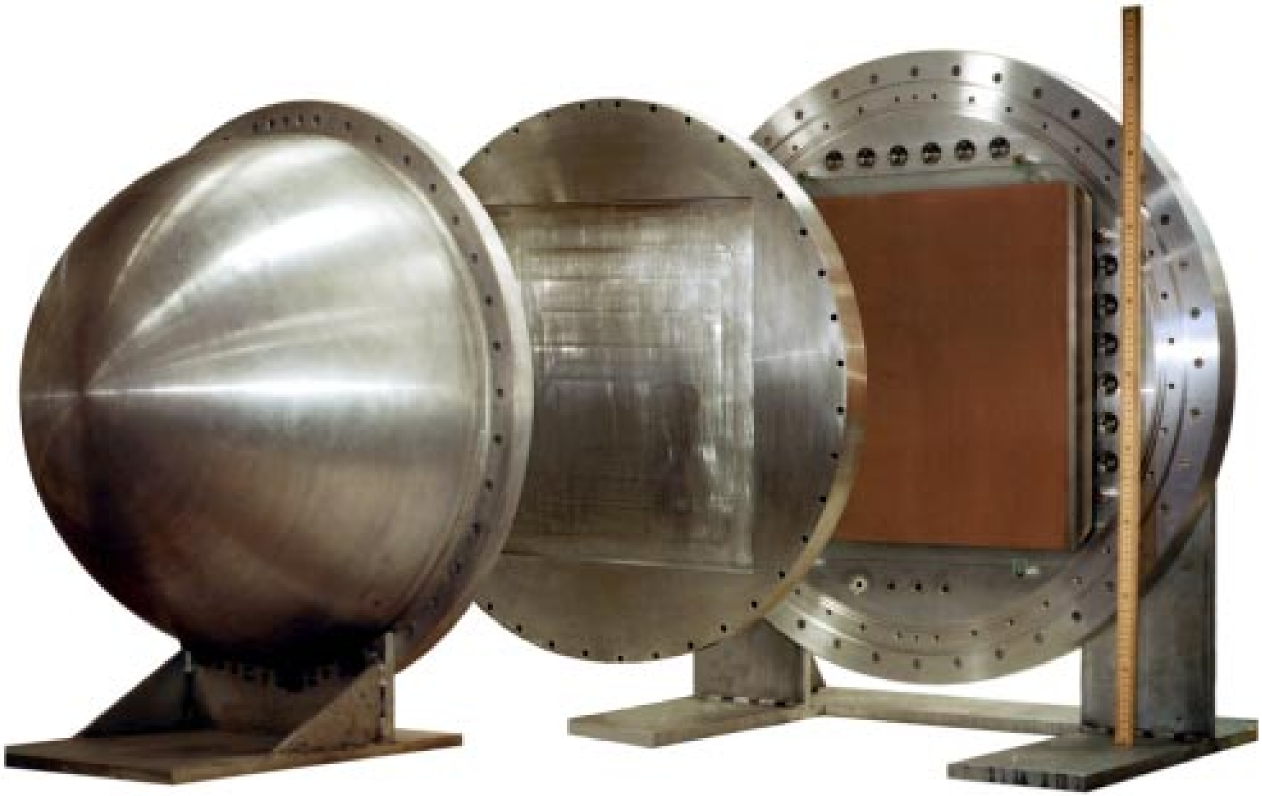
Three detector array for uses in protein crystallography. The detector shielding and position readout electronics are visible, as well as the sample goniometer.

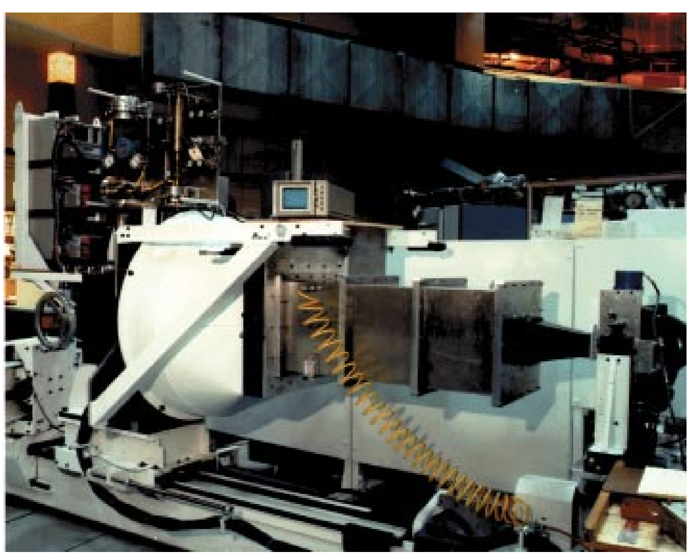
A powerful method for measuring non-linearity is provided by directing an extended, uniform intensity neutron beam across the sensing axis of a detector. The resulting spectrum is termed a Uniform Irradiation Response, the ideal being a perfectly flat response. The X-axis, along the anode wires, has very low non-linearity, as indicated in the top figure.

In the Y-axis, a new cathode wire grid arrangement has been developed to reduce significantly the non-linearity due to anode wire modulation, without degradation in position resolution. The improved performance is shown in the bottom figure.

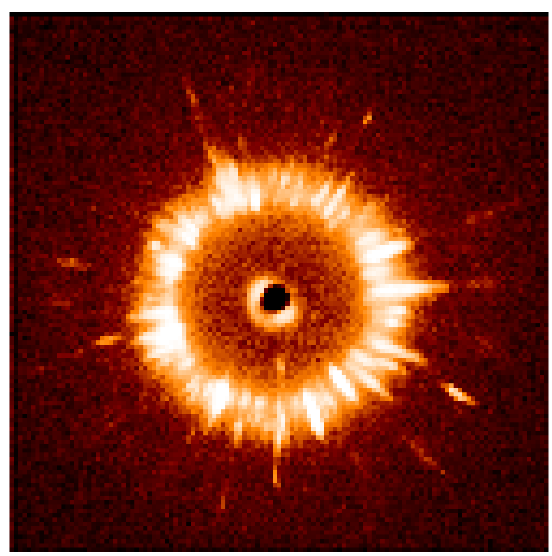


Large Area 50cm×50cm Detector





Small Angle Neutron Scattering Spectrometer, incorporating a 50cm×50cm detector (white cover to left).

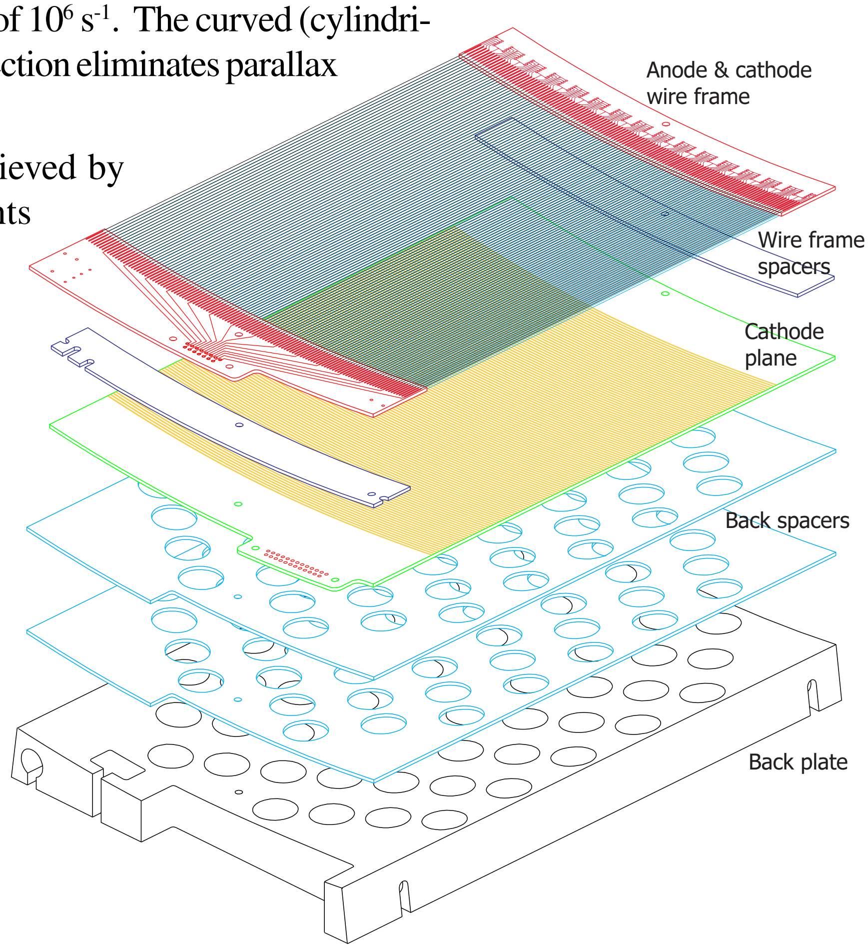


Small-angle scattering diffraction image, detailing many tiny Bragg peaks in a Debye Scherrer ring.

High Precision, Curved 150cm×20cm Detector

Neutron protein crystallography using the Laue technique provides a powerful tool for studying the dynamics and detailed structure of proteins. This type of experiment is best performed at a spallation source because neutron energies can be determined, provided a detector with appropriate timing resolution is utilized.

We are constructing a new detector for this application. To be used at a purpose designed beam-line at LANSCE at Los Alamos National Laboratory, the detector will be the most advanced device that we have built to date. It will cover an angular range of 120º at a 70cm sample to detector distance, have a collecting area of 150cm×20cm, a position resolution of 1.3 mm FWHM, efficiency 50–90% in the wavelength range 1.5–5 Å, and count rate capability in excess of 10^6 s^{-1}. The curved (cylindrical) shape along the 150cm direction eliminates parallax error.



These characteristics are achieved by dividing the internal elements into eight segments that are readout in parallel. The aluminum pressure vessel into which all eight segments fit is shown above. A single segment, outlined in diagram on right, is similar to that used in the standard 20cm×20cm detectors, but with curvature. A fast, digital center-of gravity decoder is being developed for readout. Most importantly, the wire chamber has good timing resolution, and easily permits a wavelength bandwidth of 0.15Å to be achieved, the resolution necessary for crystallography.

User Installations of BNL's Thermal Neutron Detectors

Existing Systems

	FWHM	Pressure
Macromolecular Neutron Crystallography		
• Three 20cm×20cm Detectors, 256×256 array	1.3 mm	9.5 atm.
Membrane Neutron Spectrometer		
• 20cm×20cm Detector, 256×256 array	1.3 mm	9.5 atm.
Materials Chemistry Spectrometer		
• 5cm×5cm Detector, 512×512 array	300μm	14.6 atm.
Small Angle Neutron Scattering Spectrometer		
• 50cm×50cm Detector, 256×256 array	2 mm	5.5 atm.
Chemical Crystallography		
• Three 20cm×20cm Detector, 256×256 array	1.3 mm	9.5 atm.
Spin Echo Spectrometer (NIST)		
• 20cm×20cm Detector, 256×256 array	1.3 mm	9.5 atm.

Systems Under Construction

Protein & Membrane Crystallography (LANL)		
• 120° Curved Detector, 70cm radius of curvature, 20cm height	1.5 mm	9.5 atm.
Crystal Backscattering Spectrometer (LANL/ISIS)		
• One dimensional truncated cone detector covering 336°	1°	8 atm

Performance Figures*

Position Resolution (FWHM)	< 0.4 - 2 mm
Number of Resolution Elements	from 128×128 to 4096×512
Active Area	from 5 cm×5 cm to 150 cm×20 cm
Wavelength Range	1 - 20 Å
Detection Efficiency	50 - 90 %
Counting Rate (total)	10^5 - 10^6 sec^{-1}
Counting Rate (single peak)	5×10^4 sec^{-1}
Integral Non-linearity	2×10^{-4} to 10^{-3}
Absolute Position Accuracy	30-100 µm
Stability of Origin	< 50 µm
Stability of Response (efficiency)	< 1%
Differential Non-linearity	±3%
Dynamic Range	Single Neutron Detection
Timing Resolution	~1 µs

* Not all properties listed can necessarily be achieved in one detector.

Contact Information:

For more information on BNL's thermal neutron detector program, visit our web site:

http://www.inst.bnl.gov/GasDetectorLab/NeutronDetectors/Overview.html,

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